SPECIFICATION

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[METHOD AND APPARATUS FOR OBJECTIVE MEASUREMENT OF NOISE]

Background of Invention

[0001] *Field of the Invention*

[0002] The present invention relates generally to a method and apparatus for measuring noise and correspondingly the level or loudness thereof in a product, such as a motor vehicle, during use; and more particularly, to a method for objectively monitoring and measuring the noise level and comparing the noise level to a known reference value.

[0003] *Background of the Invention*

[0004] As part of ongoing quality concerns, motor vehicle manufacturers monitor and inspect their products during and after the manufacturing process. One method of tracking vehicle quality is the use of warranty coding parameters. These parameters typically include a list of vehicle systems, individual components associated with the systems and a list of descriptors; i.e., standard descriptive words used to describe any problems or remedial action taken with respect to a particular problem. Utilizing a standard set of codes, aids in evaluating vehicle quality in a consistent and uniform manner.

[0005] Operation of a motor vehicle may result in vibrations in the vehicle that can cause noise, or more specifically undesired or unwanted sounds. These sounds are often referred to as squeaks and rattles and typically result from a particular vehicle component or combination of components. The amount of noise generated by such squeaks and rattles, particularly the level or loudness thereof generated during vehicle operation, is one quality or parameter that is monitored both during and after

manufacture.

[0006] Accordingly, in an attempt to reduce the occurrences of such squeaks and rattles and determine the cause thereof, trained inspectors randomly select and subjectively evaluate vehicles for squeak and rattle noise levels. These evaluations typically entail randomly selecting a vehicle from the assembly line. Placing the vehicle on a vibration inducing apparatus, such as a vehicle shaker or "four-poster" and activating the vibration inducing apparatus to induce vibration in the vehicle. While the vehicle is shaken or vibrated an operator or technician, sitting in the vehicle operator compartment, listens to noise level, specifically the loudness of any sound, including any squeaks or rattles, occurring in the vehicle operator compartment. After listening, the operator or technician makes a subjective determination to determine if the vehicle meets acceptable noise, vibration, harshness, squeak, and rattle levels.

[0007] Systems that use a microphone in a vehicle to obtain or record and analyze sound levels exist. Such systems typically determine the cause of the sound; i.e., they primarily function as a diagnostic tool used to locate the source of the excess sound. They do not objectively measure the sound level, nor do they analyze the data obtained by the relating the sound level to the cause thereof.

Summary of Invention

[0008] The present invention provides a method and apparatus for objectively monitoring the sound level of vibration induced sounds in a product or assembly and comparing it to a threshold level. The method includes the steps of providing a vibration generator to vibrate a product or assembly. Placing a sound recording instrument adjacent or in the product or assembly. Connecting the sound recording instrument to a data acquisition apparatus. Activating the vibration generator to induce vibration in the product or assembly and measuring and recording the sound level, specifically the loudness of the sound, occurring in the product or assembly as a result of the vibration. Obtaining an objective metric value, such as an N10 loudness objective metric, from the sound recording. Comparing the objective metric value to a predetermined threshold objective metric value selected for the product or assembly.

[0009]

When the objective metric or N10 level exceeds the threshold objective metric

value, the operator or technician then diagnoses the product or assembly to the source or cause of the undesired sound level or noise. Once the source or cause of the undesired sound level or noise is located, the operator or technician identifies the component or portion of the assembly causing squeak or rattle and performs an appropriate repair. The product or assembly is retested to confirm that the undesired sound level or noise is no longer present.

[0010] In accordance with the present invention, the recorded sound level and correspondingly objective metric value obtained are saved as raw data by the data acquisition apparatus. In addition, the operator or technician enters information into the data acquisition apparatus related to the diagnosis and repair. The diagnoses and repair information is entered using the customer concern codes or warranty parameters. Thus, information retrieved from the database relating to the products or assemblies tested is available to prepare charts and graphs relating to the source of the undesired sound level or noise; i.e., squeaks or rattles, along with the repair undertaken to correct and eliminate the undesired sound level or noise. In accordance with a further aspect of the invention, information relating to possible causes of the undesired sound level or noise is transmitted to the assembly or fabrication line and when possible, suggestions are made that may help to reduce the undesired sound or noise level.

Brief Description of Drawings

[0011] FIG. 1 is a schematic in view of an apparatus for measuring vibration induced vehicle noise or sound according to the present invention shown in use with a vehicle;

[0012] FIG. 2 is a flowchart illustrating the overall method of one embodiment of the present invention;

[0013] FIGS. 3a and 3b are flowcharts illustrating a method of measuring, comparing and storing the sound or noise level generated during vehicle vibration according to the overall method illustrated in FIG. 2;

[0014] FIG 4. is a flowchart illustrating the method of statistically analyzing the data obtained according to the overall method illustrated in FIG. 2;

[0015] FIG. 5 is a flowchart illustrating the method for providing feedback based on the analyzed data according to the overall method illustrated in FIG. 2;

[0016] FIG. 6 is a flowchart illustrating a method of computing the objective metric.

Detailed Description

[0017] FIG. 1 illustrates an apparatus or system 10 for objectively monitoring the level of sound in a vehicle 12 occurring when the vehicle 12 is vibrated to simulate on road operation according to one embodiment of the present invention. While shown for use with a vehicle 12, it should be understood that the method disclosed herein is suitable for use with any product or assembly, including any vehicle components or other products, having quality concerns relating to noise or sound levels. For instance, the method disclosed herein is useful for objectively measuring the noise; i.e. squeak and rattle of vehicle components separate and independent of the vehicle. Accordingly, evaluation of individual components for undesired sound or noise levels may take place prior to assembly in a vehicle.

[0018] As shown in FIG. 1, the vehicle 12 is placed on a vibration generator, seen generally at 14. Upon activation, the vibration generator 14, commonly referred to as a "four-poster," shakes or moves the vehicle 12 in a manner that simulates actual driving conditions. Other vibration generation systems that impart energy to a vehicle or product to simulate an in use condition of the vehicle product could also be used. In addition, it should be understood that the following method may also be used during actual operation of a vehicle. For instance, the method may be practiced when the vehicle is driven under normal roadway conditions or on a test track. Thus, as used herein, operation means either actual operation or simulated operation, i.e., when the vehicle is placed upon a vibration generator.

[0019]

The apparatus 10 includes a sound recording instrument 16 such as a microphone. The sound recording instrument 16 is attached to a signal conditioner 18 that both conditions and amplifies the signal received from the sound recording instrument 16. The signal conditioner 18 is connected to a data acquisition apparatus, such as a computer 20, typically through a microphone socket located on a sound card of the computer 20. The computer 20 disclosed herein may be either a standard

desktop or laptop personal computer having a sound card for recording sound data along with suitable memory and processing speed for storing and analyzing the sound data received from the sound recording instrument 16. The computer 20 may also include a network card enabling the computer 20 to connect to a network or mainframe 22.

[0020] Referring now to FIG. 2, a block diagram of a method 30 for measuring, statistically processing and generating feedback information based on sound levels according to one embodiment of the present invention is illustrated. In this embodiment of the present invention, the method 30 is used with an assembly/fabrication line 32 for the manufacture of vehicles 12.

[0021] In operation, the method 30 begins with block 34, wherein a vehicle 12 is randomly selected from the assembly/fabrication line 32. After positioning the vehicle 12 on the vibration generator 14, an operator or technician places the sound recording instrument 16 in the vehicle operator compartment. Typically, the sound recording instrument 16 is attached to the visor 26 located over the steering wheel 28. Thus, the sound recording instrument 16 is placed such that it records the sound or noise level in the area of the vehicle operator. It may also be placed in other locations or areas of the vehicle if desired to monitor specific vehicle components or potential problem areas. The operator then starts the vibration generator 14 to vibrate the vehicle 12. Block 36 obtains, through the sound recording instrument 16, a measured sound level within the vehicle operator compartment 24. Based on the measured sound level an objective metric is computed. In the present embodiment, the objective metric is based on a N10 loudness scale, which is a common squeak and rattle descriptor. The N10 level is that sound level reached or exceeded by ten percent of the values. Accordingly, and objective metric based on the N10 loudness scale is computed for each tested vehicle. The objective metric or N10 level for the tested vehicle is then compared to a predetermined threshold metric or threshold N10 level.

[0022]

FIG. 6 illustrates a flow diagram 90 that represents operation of the method to compute the objective metric based on the measured sound level. In operation, a block 92 divides the signal received from the sound recording instrument 16 into preferably twenty-eight equal signals. The sound recording instrument 16 signal is an

electrical signal representing audio sounds of the noise recorded from the vehicle 12. For simplicity, flow diagram 90 illustrates the processing operation of only one of the divided signals. The processing operation is the same for each of the divided signals.

[0023] Block 94 then filters the divided signal to extract signals with different frequency content. Block 94 includes a bank of preferably twenty-eight bandpass filters, known as one-third octave filters, each corresponding to a respective divided signal. Each bandpass filter receives its respective divided signal to pass a signal of desired frequency content. Preferably, the bank of bandpass filters have center frequencies from 25 Hz to 12.5 kHz.

[0024] Block 96 then extracts the envelope of the waveform of the divided filter signal. Block 98 then converts the extracted envelope to decibel (dB). Block 100 then converts the extracted envelope to an excitation level corresponding to an excitation level used in the human auditory system. The twenty-eight signals are reduced to twenty-one critical band signals according to ISO 532B. Block 102 then temporal masks the excitation levels.

[0025] In essence, blocks 96, 98, 100, and 102 model non-linear processing in the human auditory system, resulting in a time-frequency representation of the acoustic activity in the human auditory system.

[0026] Block 104 then spectral masks the critical bands; i.e., relates the masking of one critical band by neighboring critical bands. Starting at the specific loudness of the lower band, the loudness in the upper band is decreased at a rate determined by the masking slope. Accordingly, spectral masking alters the specific loudness in each masked band. Block 104 then sums the specific loudness of each critical band together to give the total loudness.

[0027] Block 106 then performs a temporal summation, or integration that step models the growth of loudness as a function of time. Finally, block 108 computes the N10 level based on the loudness of the signal received from block 106.

[0028] The threshold metric or threshold N10 level must be set for each type or model of vehicle. The threshold N10 level may be determined in several ways. One way is to randomly select a representative sample of vehicles. The sound level in these vehicles

is measured and the recorded value is used to establish the threshold metric or threshold N10 value. Another way is to have a trained technician subjectively evaluate and select a vehicle meeting the appropriate noise level standards. The sound level of this vehicle is then recorded and from that, a threshold metric or threshold N10 level is developed.

[0029] As set forth more fully below, an objective metric or N10 level corresponding to the sound level recorded by the sound recording instrument 16 is computed for each vehicle 12 tested. When the objective metric or N10 level exceeds that of the threshold metric or threshold N10 level, the operator or technician subjectively evaluates the vehicle to determine the source of the undesired sound or noise. Once the source is located, the operator or technician performs and documents any repairs necessary. Block 38 returns the vehicle to the assembly/fabrication line.

[0030] Block 40 takes the data obtained in block 36 and statistically processes the data to place the data in usable form. Charts or graphs illustrating the concerns or problems entered during or after the measurement process by the technician or operator are one method of displaying the collected data. Additional information pertaining to the tested vehicle may also be displayed, including, identification of vehicle subsystems or components causing the noise or squeak and rattle; for example: the exterior, body, hood or trunk, underbody, suspension and brakes, power train, steering, instrument panel and consoles, audio, glass or doors, seats, restraints, or other interior items not previously listed, along with a description of any repairs taken to alleviate any noise or squeak and rattle concerns.

[0031] Block 42 then generates and provides feedback to the assembly/fabrication line 32 based on the statistically processed data including any information related to the cause of the undesired sound level or noise, such as where squeaks and rattles emitted by the vehicle are occurring. The feedback may also include possible suggestions relating to manufacturing/design changes that may reduce squeak and rattle concerns.

[0032] Accordingly, the overall method the present invention is comprised of three independent parts: first, measuring the noise or sound, specifically the loudness thereof, emitted when vibrating the vehicle along with making any repairs, with

associated documentation, necessary to eliminate the noise; second, statistically processing the obtained information and generating reports, including preparing charts or graphs enabling the data to be analyzed; and third, providing feedback reports relating to cause and repairs to the assembly/fabrication line.

[0033] Turning now to FIGS. 3a and 3b, block 36 is shown in detail and begins with block 44, which provides for preparation of the vehicle 12 to be tested. The steps relating to preparation include, as set forth earlier, setting up the vehicle 12 on the vibration generator 14 or excitation fixture and removing all items on the vehicle 12 that might create random or additional noise. This includes removing any loose items in the vehicle 12 along with the plastic covers on the seats of the vehicle 12, emptying the context of the glove box, placing all the seats upright and locked in their tracks, closing the doors, hood and trunk, and ensuring that all windows are fully closed. Once initial preparations are complete, the sound recording instrument 16 or microphone is installed in the vehicle 12 and connected to the signal conditioner 18.

[0034] As shown in block 46, the operator or technician then enters the vehicle identification number into the computer 20 of using a keyboard or an appropriate graphical user interface located on the computer 20. Other information relating to the vehicle made may also be entered at this time. Block 48 sets forth the next step in the process wherein the computer 20, through an appropriate graphical user interface, prompts the operator or technician to verify the instrumentation. After verification, block 50 starts the vibration generator and initiates the measuring process. After which block 52 acquires data for a set period, the period being a suitable time for the sound recording instrument 16 to obtain the requisite sound sample. In the present embodiment, the time is fifteen seconds. Shorter or longer intervals could also be used. Block 54 then computes the objective metric or N10 level and block 56 displays on the graphical user interface the N10 loudness objective metric for the tested vehicle.

[0035]

Block 58 then determines if the acquired data is of sufficient quality. For example, a signal was present and no signal overloads were found. Block 60 then evaluates the sound level by comparing the objective metric or N10 level for the test vehicle with the threshold metric or threshold N10 level. If the value of the objective metric or N10

level is below the value of the threshold metric or threshold N10 level, the process skips to block 66 where the raw data and results are saved. If the value of the objective metric or N10 level is above the threshold metric or threshold N10 level, the process continues to block 62 where the operator or technician diagnoses and/or verifies the source of the noise; i.e., the particular squeak or rattle, and performs an appropriate repair. Once any repairs are finished, the operator or technician confirms that the noise is no longer present.

[0036] Block 64 then has the operator or technician document the diagnoses and any necessary repairs using the graphical user interface. Specifically, the operator or technician inputs, through the graphical user interface, into the computer standardized comments and descriptors relating to the system, components, and the necessary repairs. The standardized comments and descriptors correspond to known warranty code parameters enabling a comparison of test data and warranty data. Once data entry is complete, block 66 saves the raw data and results. Block 68 completes the measurement process of block 36 by removing the test vehicle from the vibration generator, putting the test vehicle in its original packaging condition and returning it to the assembly/fabrication line 32.

[0037] Referring now to FIG. 4 block 40 is shown in detail. Block 70 retrieves the data from all the tested products, which are in the instant embodiment vehicles, stored in the database. Data is extracted relating to both the threshold metric or threshold N10 level and the objective metric or N10 level obtained for each of the tested vehicles. In addition, data relating to the cause of the noise or loudness level for those vehicles whose objective metric or N10 level exceeded the threshold metric or threshold N10 level along with the repair information is obtained. Block 74 then performs a statistical analysis process on the data, including preparation of charts, graphs and histograms illustrating: the threshold metric or threshold N10 level; the objective metric or N10 levels for the tested vehicles; the reasons, specifically, an identification of the subsystems and components, that the threshold metric or threshold N10 level was exceeded; and the repairs performed by the technician or operator. Block 76 then saves the information including the data computation and any charts, graphs or histograms in a spreadsheet.

[0038] FIG. 5 shows block 42 in detail, including block 78, which extracts the repair information; i.e., those components needing repair from the spreadsheet. Block 80 inputs this information into the assembly/fabrication line quality system. Block 82 transmits the information to the appropriate supervisor or operator. Finally, block 84 then provides possible suggestions or manufacturing/design improvements to fix or eliminate those problems causing the undesired sound or noise detected during the measuring process.

[0039] The invention links the objective measurements with the subjective identification of concerns, i.e., the specific location or source of the undesired sound or noise, using standard customer concern codes (CCC's), to provide a database for prioritizing manufacturing process and product design improvements. This data is also used for tracking quality trends over time, too quickly evaluate and quantify the effectiveness of improvement actions. Using standard Customer Concern Codes enables this data to be directly related to information obtained from existing warranty tracking systems and customer satisfaction surveys. In addition, descriptions of concerns frequently differed between operators, often leading to a failure to specifically identifying significant concerns. Thus, use of standard CCC terminology enables greater accuracy and consistent identification of concerns that correspondingly leads to more effective prioritization of improvement actions.

[0040] It will thus be seen that the objects of the invention have been fully and effectively accomplished. It will be realized, however, that the foregoing specific embodiments have been shown and described for the purposes of illustrating the functional and structural principles of the invention and is subject to change without departure from such principles. Therefore, this invention includes all modifications encompassed within the scope of the following claims.